Comparison of the HadGEM2 climate-chemistry model against in-situ and SCIAMACHY atmospheric methane data

G. D. Hayman et al.

We thank the reviewers for their comments and are very pleased that both reviewers recommend publication. Our responses to the review comments are given below.

Anonymous Referee #1

This study has evaluated wetland CH4 emission estimates from the UK community land model JULES by comparing model simulations with in-situ and satellite observations of atmospheric CH4 concentrations. Their results highlight the large uncertainties in the current estimates for wetland CH4 emissions, as well as the potential for using space-based observations of atmospheric CH4 columns to evaluate land surface models. This paper is well written, and very informative. It should be accepted for publication in ACP after some minor changes.

Major comments:
1. The authors have shown that the HadGEM2 CH4 simulations have a much steeper fall-off in the upper troposphere and stratosphere than the (ACE/HALOE) observations, resulting in a model underestimation of XCH4 columns by about 50ppb when compared to SCIAMACHY retrievals. However, it is interesting to know the comparisons of the annual growth rates (as well as the annual cycles) derived from their un-constrained and constrained HadGEM2 XCH4 simulations, so that we can further understand how the issues with model CH4 simulations in the upper troposphere and stratosphere will affect the comparisons of model simulations with space-borne observations.

Response:

Figure 10 in the paper shows a comparison of time series and annual cycles of the observed atmospheric methane columns (XCH4) from SCIAMACHY and those derived from the HadGEM2 runs, constrained with the HALOE/ACE-assimilated TOMCAT output. We will include in the Supplement an equivalent comparison for the same runs using the unconstrained model results, make reference to it in either Section 3.2.1 or 3.2.2 and expand the discussion in Section 4.1 (see also response to 2 below).

2. While the HadGEM2 run using JULES-GIEMS wetland emissions shows better agreement with in-situ observations, simulations forced by the FUNG emission inventory seem to score much higher in the comparisons against SCIAMACHY over Northern Hemisphere. Here, more detailed explanations are needed: for example, whether it is related to the transport model errors, or it is caused by the use of constrained HadGEM2 simulations.

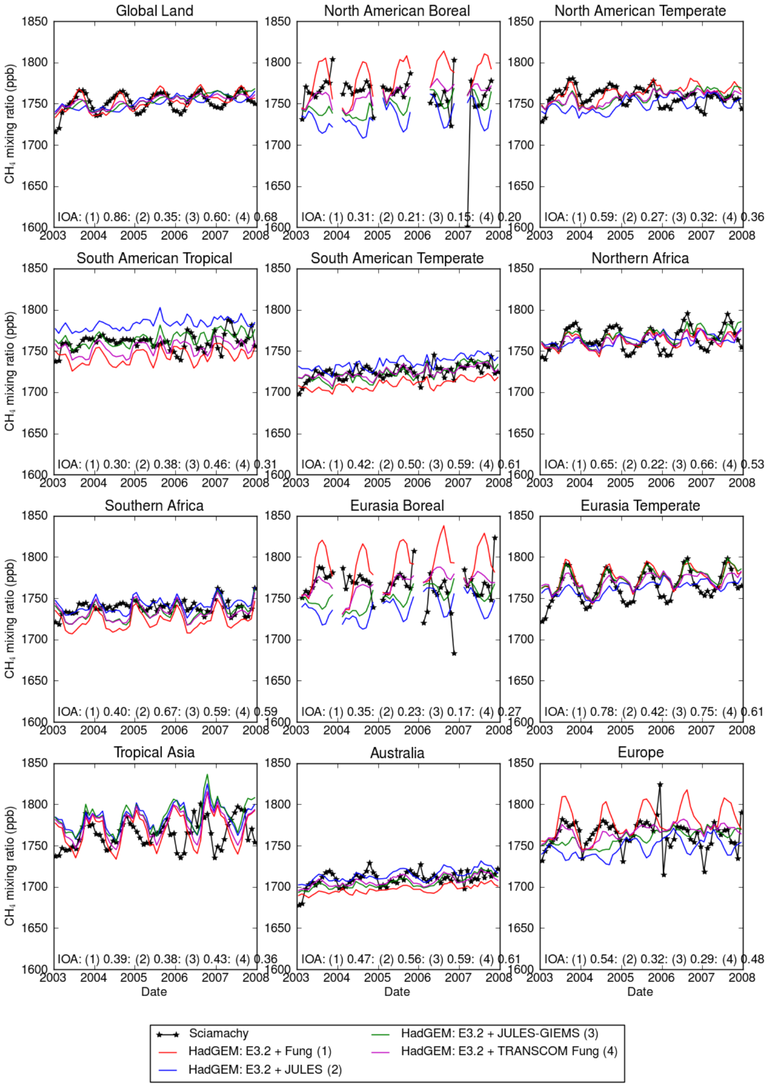
Response:

This is linked to the previous comment comparing the HadGEM2 outputs using the constrained and unconstrained outputs. The following figures show a comparison of the time series of the observed and modelled atmospheric methane columns for the constrained (Panel a of Figure 10 in the paper) and the unconstrained model outputs. We will expand the discussion in Section 4.1 to show that the tendencies in the metrics used are similar for the constrained and unconstrained outputs, suggesting that the different wetland emission inventories largely explain the performance against the atmospheric column measurements.

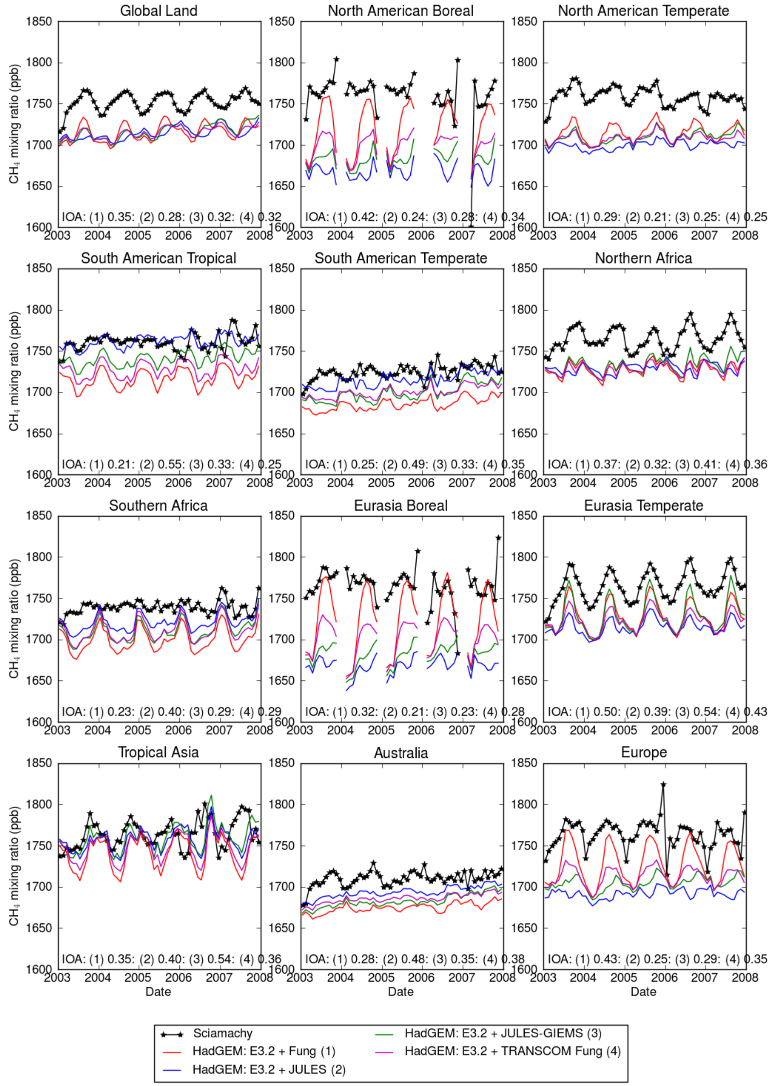
In our response to the other Reviewer (see below), we have since undertaken a run using the FUNG inventory prepared for the TRANSCOM methane model intercomparison (cited paper by Patra et al., 2011), scaled to give an annual emission estimate of 181 Tg per annum. This has lower boreal emissions than our FUNG inventory and this may explain the ‘apparent’ good performance against the SCIAMACHY atmospheric column measurements. The following figures also include this new model run. We will include the output of this run in the revised paper and discuss it where appropriate.

We will also include some discussion on the consistency of the comparisons with the surface atmospheric methane concentrations and the atmospheric column methane measurements.

XCH4 - HadGEM2 constrained with HALOE/ACE assimilated TOMCAT



XCH4 - HadGEM2 unconstrained



Minor comments:
1. Line 16, Page 11: 'The WFM-DOAS algorithm is one of : : :'. Some introductions on the quality of the WFMFv2.3 XCH4 retrievals (such as the biases at different latitude bands) will be helpful.

Response:

The validation of the WFM-DOAS v2.3 XCH4 dataset has been published in Dils et al. (2014). The biases at all individual TCCON stations are listed in Table 7 of the paper. The relative accuracy, which is the relevant quantity to measure the variability of the regional biases, is 7.8 ppb for WFMD. We will amend Section 2.2.2 (page 12977), where the SCIAMACHY XCH4 product is described.

"The WFM-DOAS algorithm is one of the algorithms currently being compared in the ESA project: Greenhouse Gases Climate Change Initiative (GHG-CCI; Buchwitz et al., 2013). **The SCIAMACHY dataset has been validated and its relative accuracy, a quality measure quantifying regional biases, is 7.8 ppb (Dils et al., 2014)**."

We will add the paper to the References:

Dils, B., Buchwitz, M., Reuter, M., Schneising, O., Boesch, H., Parker, R., Guerlet, S., Aben, I., Blumenstock, T., Burrows, J. P., Butz, A., Deutscher, N. M., Frankenberg, C., Hase, F., Hasekamp, O. P., Heymann, J., De Mazière, M., Notholt, J., Sussmann, R., Warneke, T., Griffith, D., Sherlock, V., and Wunch, D.: The Greenhouse Gas Climate Change Initiative (GHG-CCI): comparative validation of GHG-CCI SCIAMACHY/ENVISAT and TANSO-FTS/GOSAT CO2 and CH4 retrieval algorithm products with measurements from the TCCON, Atmos. Meas. Tech., 7, 1723-1744, doi:10.5194/amt-7-1723-2014, 2014.

2. Figure 3: I am not sure why sin(latitude) instead of latitude is chosen as x-axis. Also, it would be easier for the reader to see if the dots are connected with (coloured) dashed lines.

Response:

Figure 3 uses sin(latitude) for the x-axis as this weights by area and emphasises the tropical regions. We will replace the figure using latitude for the x axis (this makes no real difference to the plots) and we will add dotted lines.

3. Line 24, Page 15: 'suggesting the annual pattern of non-wetland methane emissions may not be correct : : :', It will help the reader to understand if the authors can present the contributions from different emission categories to the observed CH4 concentrations over one or two selected sites.

Response:

The HadGEM2 model configuration used in this work is not set-up to give tracers, which tag or colour specific methane emission sectors. We have therefore selected a number of surface atmospheric methane sites (e.g., Barrow and Plateau Assy in Figure 6) and derived the contribution of the different methane source sectors to the overall emissions. This will be included in the revised paper.

Anonymous Referee #2

A study by G. Hayman and co-authors makes an attempt to use Sciamachy observations of atmospheric methane as a tool for evaluating the JULES model simulated methane emissions from wetlands. The use of the satellite data to get the information about fluxes in areas remote from the observations has been tried before in the frame work of inverse modeling, but this study use the observations directly to compared with transport model simulated fields. This makes a step towards wider use of the remote sensing data from Sciamachy and other missions for validation the ESM-estimated CH4 fields, reducing the space for uncertainties of the simulated fluxes in the tropical and subtropical regions where the wetland emissions are high. Authors showed good amount of effort and creativity dealing with difficult problem of simulating stratospheric CH4 content. There are some weaker points in the study design, such as the choice of the FUNG emission scenario, which doesn't seem optimal in high latitudes, as better results were reported with other datasets, notably by Patra, et al, (2011) Overall the paper is well written and provided a valuable contribution. I recommend to publish it after minor corrections.

Response:

As indicated in the paper, we used an implementation of the Fung wetland methane inventory for consistency with other work (as reported subsequently in O'Connor et al., Geoscientific Model Development, 2014, doi:10.5194/gmd-7-41-2014). O'Connor et al. (pages 63-64) found that the 'modelled surface concentrations are overestimated by approximately 10% during the Northern Hemisphere summer and autumn. A similar positive bias, albeit reduced, is also evident in the comparison at Mace Head'. Further in the same paragraph, O'Connor refer to this paper: 'More recent work by Hayman et al. (2014) also supports the hypothesis that the strength of the Fung et al. (1991) wetland emissions in the Northern Hemisphere (as used in this study) are overstated.'

We acknowledge in the present paper that this was an incorrect interpretation of the dataset. It results in much higher wetland emissions for boreal and higher latitudes, which is apparent in the comparisons with the surface atmospheric methane measurements and the atmospheric column methane observations. Although the dataset of Fung et al. was produced in the late 1980's/1990's, it is still widely used within the atmospheric chemistry community and provided the base wetland methane emission estimate for the TRANSCOM CH_4 model intercomparison (Patra et al., 2011 mentioned above).

In response to this comment, we have since undertaken a new model run using the Fung wetland inventory developed for the TRANSCOM CH4 model intercomparison (scaled to give annual wetland methane emissions of 181 Tg CH_4 yr^{-1}). We will include this new model run in the revised paper as appropriate.

Detailed comments
Page 12988, line 12, Providing a numerical value for annual stratospheric loss rate would give some extra sense to the discussion on simulated stratospheric methane content.

Response:

We have calculated the global annual loss rate of stratospheric CH_4 (53±4 Tg CH_4 yr^{-1}) and compared it with other published estimates. We will alter the description of the UKCA tropospheric chemistry scheme (Section 2.1.2) and add the following to the current Section 3.2.1:

In the model runs carried out here, we derive the global annual loss rate of stratospheric CH_4 to be 53±4 Tg CH_4 yr^{-1}. This is higher than previous estimates (40 Tg CH_4 yr^{-1}, from Ehhalt et al., 2001). Similar behaviour has however been seen in the stratospheric configuration of UKCA (Morgenstern et al., 2009). Given the different treatment of stratospheric CH_4 removal in the two UKCA configurations and that stratospheric chemical removal rates are much slower than transport timescales (Zahn et al., 2006), it is likely that the faster fall-off of modelled stratospheric CH_4 with height than observed is an indication that stratospheric transport timescales are too long.

Page 12988, line 5, Is it better to say "mapping-based" instead of "mapped-based"?

Response: Accept

Page 12988. When comparing with Amazon emissions it is useful to add comparison to results by Beck, V., et al., (Atmos. Chem. Phys., 13, 7961-7982, 2013)

Response:

Beck et al. (2013) derive emission estimates for the Amazon lowland region from measurements made during the BARCA aircraft campaign during the months of November 2008 and May 2009. The mean monthly CH_4 budget for the Amazon basin obtained from four different simulations is 3.3 Tg (range 1.5-4.8 Tg) for November 2008 and 3.3 Tg (range 1.3-5.5 Tg) for May 2009. We have extracted the wetland methane emissions for the months of May and November (average between 1999 and 2007) for the JULES and JULES-GIEMS wetland emission inventories for a rectangular domain closely approximately the irregular Amazon lowland domain used by Beck et al. and find:

- JULES May: 6.5 Tg CH_4, November: 5.7 Tg CH_4
- JULES-GIEMS May: 3.9 Tg CH_4 November: 2.2 Tg CH_4

The JULES-GIEMS emission estimate is within the range given by Beck et al. but the JULES is higher. As we state in the paper, the JULES wetland emissions are too high in this region.

We will include this paper in the discussion of Section 4.2 on comparison with other wetland estimates and add an entry to Table 2.

Page 12986, line 24. A need to reduce non-wetland emissions over India was cited by Patra et al, (J. Meteorol. Soc. Jpn., 87(4), 635-663, 2009), adding the citation may help convincing the reader that the JULES estimates are going in right direction.

Response:

We thank the reviewer for this. We will add a sentence to the end of Section 4.1 that Patra et al. (2009) also found that the emissions in the Indian Ganges region were overstated.